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Development of a Taxonomy of Human Performance:

An Information-Theoretic Approach

Jerrold M. Levine

Warren H. Teichner

Technical Report 9

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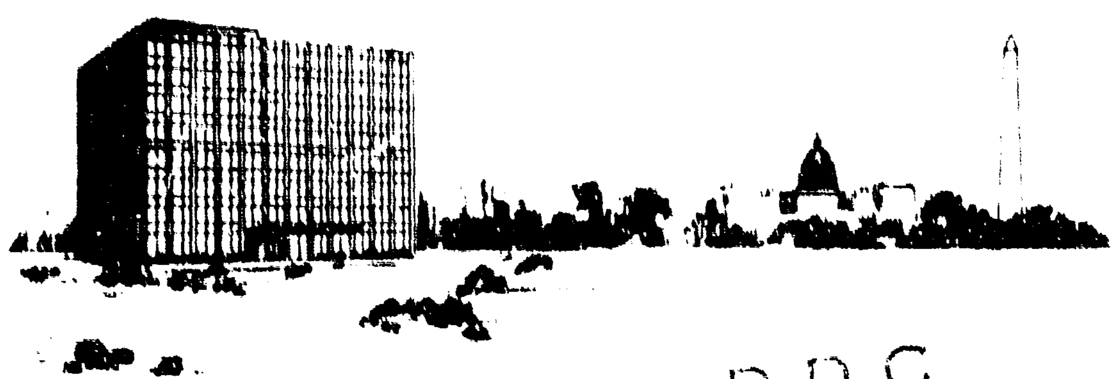

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13. ABSTRACT

The development and evaluation of systems for describing and classifying tasks which can improve generalization of research results about human performance is essential for organizing, communicating, and implementing these research findings. The present research was undertaken to develop one such system which is based on an information processing model.

A theoretical model for task classification, generated as one of several approaches to development of a taxonomy of human performance, is presented. The model defines a task as an information transfer between a source and a receiver. It is postulated that classes of tasks are characterized by classes of constraints (restrictions on random sampling) and that these constraints can be conveniently and rationally dichotomized into those acting upon the source (input) and receiver (output) of the information. Within each class of tasks so defined, tasks are further characterized in terms of the effect of amount of redundancy upon information transmission and in terms of the relationship between input and output uncertainty.

A method for empirical evaluation of the model is described in terms of a two-fold iterative procedure: computer simulations of sampling constraints to determine the relationships between redundancy and transmitted information under a variety of constraint combinations; a series of empirical investigations using tasks which allow the experimenter to manipulate input constraints and require the subject to provide output constraints.

This information processing model for task classification has the potential of predicting performance on tasks which have not yet been researched and for hardware that is not yet built, and of facilitating integration and generalization of human performance research findings.

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TECHNICAL REPORT 9

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Principal Investigator: Edwin A. Fleishman

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Washington Office

February 1971

PREFACE

The AIR Taxonomy Project was initiated as a basic research effort in September 1967, under a contract with the Advanced Research Projects Agency, in response to long-range and pervasive problems in a variety of research and applied areas. The effort to develop ways of describing and classifying tasks which would improve predictions about factors affecting human performance in such tasks represents one of the few attempts to find ways to bridge the gap between research on human performance and the applications of this research to the real world of personnel and human factors decisions.

The present report is one of a series which resulted from work undertaken during the first three years of project activity. In 1970, monitorship of the project was transferred from the Air Force Office of Scientific Research (AFOSR) to the U. S. Army Behavior and Systems Research Laboratory (BESRL), under a new contract. This report, completed under the new contract, is among several describing the previous developmental work. It is also being distributed separately as a BESRL Research Study.

Edwin A. Fleishman

EDWIN A FLEISHMAN
Senior Vice President and
Director, Washington Office
American Institutes for Research

FOREWORD

The American Institutes for Research is engaged in a research program to develop and evaluate new systems for describing and classifying tasks which can improve generalization of research results about human performance and to develop a common language for researcher-decision maker communication that would help organize human performance information for maximum use in training, equipment design, and personnel selection.

The objective of this program is to develop theoretically-based language systems (taxonomies) which--when merged with appropriate sets of decision logic and appropriate sets of quantitative data--can be used to make improved predictions about human performance. Such taxonomies should be useful, for example, when future management information and decision systems are designed for Army use.

The present publication reports on an effort to develop a theoretical model, based upon information processing concepts, which would serve to classify tasks so as to permit the prediction of performance on new tasks based upon data from similar tasks. The particular language system discussed is most useful in its application to equipment design problems which must consider performance in man-machine interactions.

J. E. UHLANER, Director
U.S. Army Behavior and Systems
Research Laboratory

DEVELOPMENT OF A TAXONOMY OF HUMAN PERFORMANCE:
AN INFORMATION-THEORETIC APPROACH

BRIEF

Requirement:

The development and evaluation of systems for describing and classifying tasks which can improve generalization of research results about human performance is essential for organizing, communicating, and implementing these research findings. The present research was undertaken to develop one such system which is based upon an information processing model.

Procedure:

A theoretical model for task classification, based upon information processing concepts, has been generated as one of several approaches toward the development of a taxonomy of human performance. The model defines a task as an information transfer between a source and a receiver. It is postulated that classes of tasks are characterized by classes of constraints (restrictions upon random sampling) and that these constraints can be conveniently and rationally dichotomized into those acting upon the source (input) and receiver (output) of the information.

Within each class of tasks so defined, tasks are further characterized in terms of the effect of amount of redundancy upon information transmission and in terms of the relationship between input and output uncertainty. It is proposed that all tasks falling within a constraint class will be more like one another than tasks in different classes. It is anticipated that all tasks falling within a constraint class will exhibit similar functional relationships between redundancy and information transmission and that these functional relationships will differ across constraint classes.

A method for empirically evaluating the model is described in terms of a twofold iterative procedure. On the one hand, the relationships between redundancy and transmitted information under a variety of constraint combinations would be derived from computer simulations of

sampling constraints. On the other hand, a series of empirical investigations would be accomplished using tasks which allow the experimenter to manipulate input constraints and require the subject to provide output constraints.

Findings:

The research effort has not yet reached the evaluative phase. This report describes only the model development efforts and the procedure for testing its viability.

Utilization of Findings:

The present model for task classification has the potential of predicting performance on tasks which have not yet been researched and for hardware which is not yet built. An analysis of the potential constraints on the task can be made and related to tasks of similar constraint composition, for which performance data is available, in order to predict performance on the new task. Furthermore, integration and generalization of human performance research findings can be facilitated by this classification scheme.

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CONTENTS

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INTRODUCTION

The American Institutes for Research is conducting research aimed at the development of a variety of provisional taxonomic schemes which contain unifying dimensions allowing one to relate the human performance observed in one situation to new situations. These approaches consider a taxonomy of human performance which can serve as a basis for describing human tasks. The value of such a taxonomy lies in problem areas which include system design, job definition, selection and training, and standardizing performance measurement and methods of study.

Several approaches to the development of a taxonomy, each geared to different problem areas and different applied and basic research users, were conceptualized under the present project and research was conducted to assess the validity and reliability of these schemes. (For summaries, see Fleishman, Kinkade, & Chambers, 1968; Fleishman, Teichner, & Stephenson, 1970; Fleishman & Stephenson, 1970.) One of these approaches, the "ability-requirements approach," described a task in terms of the human abilities required to perform it, such that the entire task could be described in terms of a profile of basic abilities which accounted for performance on the task. Performance would be expected to be highly similar for tasks which call for similar patterns of abilities. If tasks were evaluated in terms of required abilities, then performance on new tasks could be predicted from tasks with similar ability requirements and classified according to ability profiles (Theologus, Romashko, & Fleishman, 1970; Theologus & Fleishman, 1971).

A second approach to the taxonomy problem, known as the "task-characteristics approach," attempted to predict performance on tasks on the basis of a set of task characteristics and to classify tasks on the basis of similarities in their profile of characteristics (Farina & Wheaton, 1971). This technique permits the prediction of performance

on new tasks on the basis of the characteristics of that task without specific reference to the human abilities required for task performance.

Several other approaches to task classification have been developed under the present project. Miller (1969) considers task strategies used by information processors during task performance. By observing and evaluating strategies and translating them into information processing terms, common principles across tasks can be derived for the purpose of task classification. Teichner and Olson (1969) use a criterion measure classification scheme in order to define basic performance categories (i.e., tracking, switching, searching, coding) for the purpose of classifying tasks. A demonstration of the feasibility of this approach appears in Teichner and Whitehead (1971).

The present paper discusses the initial development of a quite different approach to the development of a task taxonomy. This approach, called an "information-theoretic approach," is based upon an underlying theoretical model which provides for a systems language common to all tasks. The purpose of this report is to describe the rationale behind the development of this approach, to discuss the underlying model, and to present a systematic empirical plan for evaluating its feasibility.

BACKGROUND AND RATIONALE

A common approach to task classification provides functional descriptors, e.g., tracking tasks, computational tasks, gating tasks. There is a certain utility in this approach providing the task categories are reasonably mutually exclusive, and providing that one does not take them too seriously. The important issue concerns the relationships and parameters on which performance depends. There is, after all, no point to classifying tasks at all except to be able to denote the relationships involved when a new task is classified.

Teichner and Olson (1969) defined all tasks as information transfers and then attempted to identify functional task categories as classes of information transfer. This is an approach that starts with the empirical side of things and builds up to abstract concepts. It goes from the specific to the general. After describing the rationale Teichner and Olson (1969) used we will proceed to outline a more theoretical approach, i.e., one that proceeds from the abstract to the empirical. Both are based upon the same fundamental definition of a task as an information transfer.

Taxonomy As a Model

Figure 1 considers both the man and the machine as components of a system. In terms of this conventional diagram, we can think of information or data as being transmitted between components and as being operated upon or processed within components. Any operation on information within a component is a process. A task may be defined as a transfer of information between components. However, what is to be called a process and what is to be called a task depends upon the level of system analysis being employed. When Figure 1-A is analyzed into its subsystems, as in Figure 1-B, what was a process at the more general descriptive level becomes a task. That is, there are now new transfers of information between components which did not exist in Figure 1-A.

FIGURE 1-A

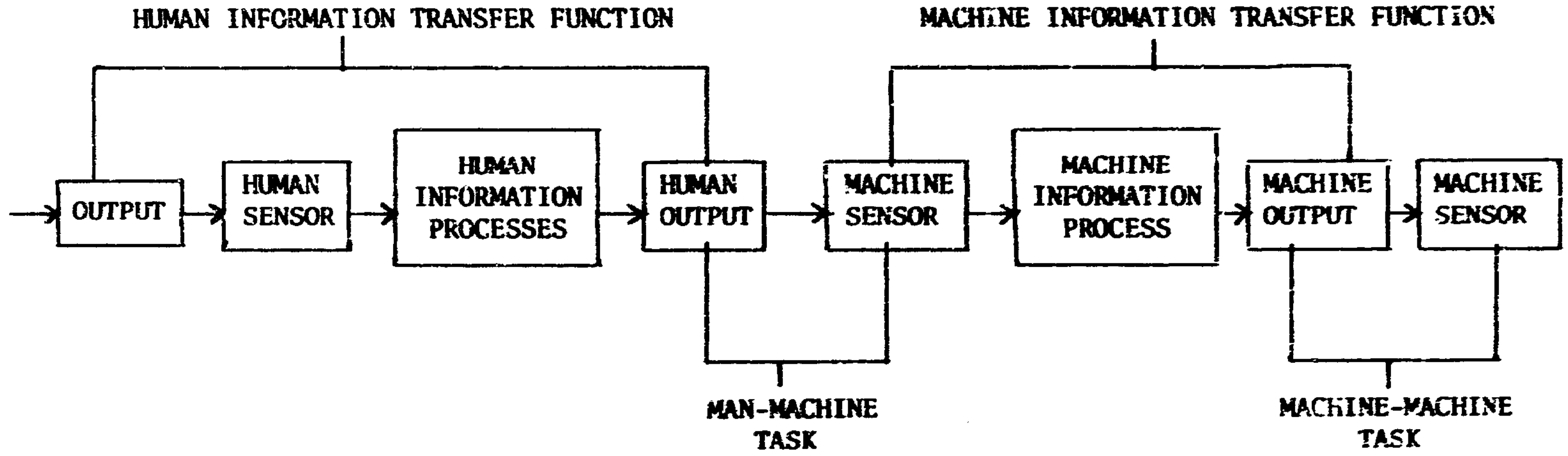


FIGURE 1-B

Figure 1. Man-machine system at two levels of description

Clearly, a process is carried out as a subtask. As the level of analysis becomes more detailed, successive processes break down into tasks.

It is convenient, but not a requisite, to deal with the transfer of information between each two successive components separately, i.e., in terms of the four major tasks, machine-man, man-man, man-machine, machine-machine. Although the psychologist is not concerned with machine-machine tasks, it is important to note that such tasks exist. That is, the concept of a task is not one which necessarily involves people. This is extremely important, and usually ignored. It just will not do to have more than one definition of a concept. Regardless of how we define task, we must be willing to use the concept wherever it fits and to say that the same relationships and parameters are involved in every single instance which falls within a task category. Furthermore, one must be willing to talk about tasks at any level of analysis. For the definition just presented, this means that what are usually vaguely referred to as "underlying processes" must be describable in exactly the same terms as tasks at less detailed levels. Thus, there are tasks between components within the central nervous system as well as between machine components, and between men and machines.

Starting with this as a rationale, Teichner and Olson (1969) defined four classes of task: searching, switching, coding, and tracking. They attempted to provide operational definitions for each and then to consider the parameters and relationships which would justify them as unique. This approach is one which takes maximum advantage of what are already determined empirical relationships. It has the disadvantage that the task classifications can never be any more reliable than the state of knowledge about these relationships.

The same problem can be approached with a model or a set of abstract concepts for which the relationships within a class are defined. Such an approach is completely reliable, but of course the model may not fit, in which case it has no validity. The model we have chosen is an

information transfer model and the approach is complementary to that of Teichner and Olson (1969).

We start with the understanding that a taxonomy is a model. It contains definitions and relationships, i.e., a logic. A classification system, ideally, is what is evolved or derived from the taxonomy when the model is applied to an empirical area of interest. If the model fits for situations involving people, then it is useful for that purpose and people can be said to be involved in tasks as defined. The model may fit situations which do not involve people, however, and these too would be called task situations in which people make responses. But we do not restrict our definitions to just those situations.

Information Theory Relevant for the Taxonomic Model

Since the model is based upon the concepts and metrics of information theory, a brief overview of the basic ideas of this theory is presented below.

Information theory is a mathematical model wherein the concept of information is formalized and quantified. Any communicative act provides information insofar as it reduces a condition of ignorance or uncertainty about the state of things under consideration. The amount of information conveyed is determined by the amount of input uncertainty which existed prior to the communicative act. The amount of information is the amount by which the uncertainty has been reduced.

The uncertainty about the outcome of any act is quantitatively related to the number of possible outcomes that exist and the probability associated with the occurrence of each of these outcomes as shown below:

$$H = - \Sigma p_i \log_2 p_i$$

where H = average uncertainty
and p_i = probability of the occurrence of the i^{th} event.

Maximum uncertainty exists whenever all possible outcomes of the event are equiprobable. Redundancy is a measure of the difference

between actual and maximum uncertainties expressed as a percentage of present to possible uncertainty ($R = 1 - H/H\ max$).

If events were presented to individuals who, in turn, were required to respond differently to the unique events, the concept of information transmission (H_t) could be employed as a measure of the discriminating ability of the human subject. Transmitted information is that portion of the uncertainty in the stimulus which is reduced (reflected in the response).

With these concepts defined, let us now turn to the model.

THE INFORMATION MODEL

We define a task as a transfer of information between an information source and a receiver in any system that can be construed as a communication channel (Shannon & Weaver, 1949). The source information, H(X), is a function of the number of alternative events contained in the source and their probabilities. The receiver information, H(Y), is defined in terms of the number of events the receiver can exhibit and their probabilities. The amount of information transmitted, H(XY), is a function of the joint probabilities of selecting source events and observing receiver events.

Classification in Terms of Constraints

We have postulated that all tasks can be characterized as imposing constraints which are simply restrictions placed upon the random sampling of stimulus and response events at the source and on the part of the receiver (Garner, 1962). These constraints can be thought of as the structure which defines the task as being in some way a unique situation. The precise specification of the stimulus configuration, the response ensemble, and the operator requirements necessary to optimize behavior determine the task's constraints. Such categories of constraint will serve as our first major dimension of classification tasks. That is to say, classes of tasks will be established on the basis of classes of constraints.

There are two general types of constraints. Constraints may be restrictions on how events from a population are sampled or restrictions on which particular events are sampled. In addition to these general types, there is a further breakdown of classes of constraints. Constraints operate upon the source (input) and receiver (output). Thus, a second major dimension of task classification is whether a constraint at the input or output is operating in the task. Examples of such constraints include rate of input, size of input, range of input-stimuli, etc. Similar constraints may operate on the output.

A constraint, then, is some kind of limitation imposed upon the input and/or output of a system. Input constraints relate to restrictions on the random generation of stimuli and the size of the stimulus ensemble. In order to constrain the input, the stimuli of the task must be either a smaller sample of some total stimulus population as perceived by the receiver or an entire stimulus population, but one whose individual stimuli occur with unequal probabilities. Output constraints, with the exception of the specification of the response ensemble, are imposed by the receiver of the stimulus set. These constraints are imposed in an attempt to structure performance in accordance with the requirements of the task. Such constraints are sampling restrictions implemented by the receiver either purposely to satisfy task requirements or necessarily as a result of the receiver's limitations in the receipt or processing of stimuli from the source.

Classification in Terms of Redundancy

A third dimension of task classification is redundancy. Constraints, whether they are imposed upon input or output, introduce redundancy into the information contained in the stimulus and/or response sets. This redundancy is created whenever any selection process (sampling from a population) retains maximum uncertainty while reducing actual uncertainty. Redundancy can vary in *form* and *amount*. The particular form of redundancy is determined by the *specific* sampling rule through which the constraint operates. The precise amount of redundancy is simply a function of the number of alternatives in the stimulus or response sets relative to the number in the population, and their probabilities of occurrence. Redundancy, then, is introduced into input information when the stimuli generated occur with unequal probabilities, or are a smaller set of stimuli than *could* have been generated from the population. Redundancy is generated in output information in a like manner.

Given any constraint on input and/or output, we postulate that tasks can be classified in terms of the effects of increasing amounts of redundancy upon information transmission between the source and receiver.

Further, we are hypothesizing that different constraint classes will generate <u>forms</u> of redundancies which will differentially influence information transmission. We would expect that certain constraints introduce a form of redundancy such that increasing amounts enhance performance, while increasing other forms of redundancy results in degradation of performance.

<u>Input-Output Relationships for Task Classification</u>

So far we have been considering only the initial input and the final output of a communication system. In the human situation this is, of course, a traditional S-R relationship. We are now calling it a task. The S-R relationship depends upon underlying processes. When we say this, however, all we are saying is that there are a series of intervening tasks. We call them "processes only" when the level of analysis is so gross as to leave them unspecified, as is the case with S-R relationships. Analysis at the S-R level, however, offers some interesting possibilities for raising questions about underlying processes in a rational way.

The fourth and final task classification dimension is the relation between quantities of input and output information. In addition to the relationship between amount of redundancy and information transmission within a constraint class, we will be interested in comparing the amount of input information to the amount of output information after task performance is completed. It is possible that output information may be less than, equal to, or greater than input information and the relationship between redundancy and information transmitted may differ as a function of this additional parameter. Furthermore, the tasks themselves may be categorized into those requiring information conservation ($H_{out} = H_{in}$), information reduction ($H_{out} < H_{in}$), or information creation ($H_{out} > H_{in}$), as demonstrated by Posner (1964). Categories within the classification include the following task characteristics:

1. <u>There can be less information in the output than in the input</u>; that is, the amount of information transmitted is less than the maximum possible. This implies constraints present in the receiver not present at the source. For illustration, suppose that it could be determined that a range type of constraint were present and that it could not be accounted for by known range type constraints such as in the eye, the empirical attention span, etc. Under these conditions, it might be inviting to postulate the presence of an underlying mechanism with properties that impose a range type of constraint. We might call this mechanism <u>attention</u> and then we might either develop a model of it which provided the needed constraint or we might try to apply available models--for example, a particular kind of band-pass filter.

2. In an S-R analysis <u>there can be more information at the receiver than at the source</u>. This can happen only if the communication system has more sources than are accounted for. If there is only one external source, other sources must be internal to the receiver. An example of how this could happen might be the following: The input from a second source might be contingent upon the occurrence of events from the first source and the receiver reports both. In this case, if the second source were internal, it might be called memory. Another example might be as follows: Successive inputs from a single source might be operated upon internally to produce a third event and the receiver reports them all. In a human performance situation, the source might present the numerical events 2 and 3, and the receiver might report "2 and 3 are 5." A process that could be postulated to provide this third event might be called computation.

3. Finally, <u>the output information might equal the input information</u>. In this case, there may be no need to assume any receiver constraints to be operating.

Summary of the Model

To summarize, we are taking an information processing approach to task classification. We have a theoretical model which defines a task as an information transfer, we postulate that classes of tasks are characterized by classes of constraints (restrictions on sampling) and that these constraints can be conveniently and rationally dichotomized into constraints upon the source (input) and receiver (output) of the information. Within each class of tasks so defined we propose to characterize tasks further in terms of the effect of amount of redundancy upon information transfer and in terms of the relationship between input and output uncertainty. It is proposed that all tasks falling within a constraint class will be more like one another than tasks in different classes. It is anticipated that all tasks falling within a constraint class will exhibit similar functional relationships between redundancy and information transfer and that these functional relationships will differ across constraint classes. Figures 2, 3, and 4 summarize the model and its dimensions of classification.

If we can establish a valid system of classification based on such an information model, then any new task can be classified on the basis of the constraints imposed on input and output, the amount of redundancy in the stimulus configuration and response ensemble, and the relationship between input and output uncertainty.

We have presented only the barest outline of a task taxonomy model, and that only in terms of some definitions. The model must also have a logic. This is given by a statement of the dependency of information transfer on the constraint classes at different levels of redundancy. The model needs to be developed in detail and then tested against human performance situations. We shall try to indicate briefly how the model can be developed and evaluated.

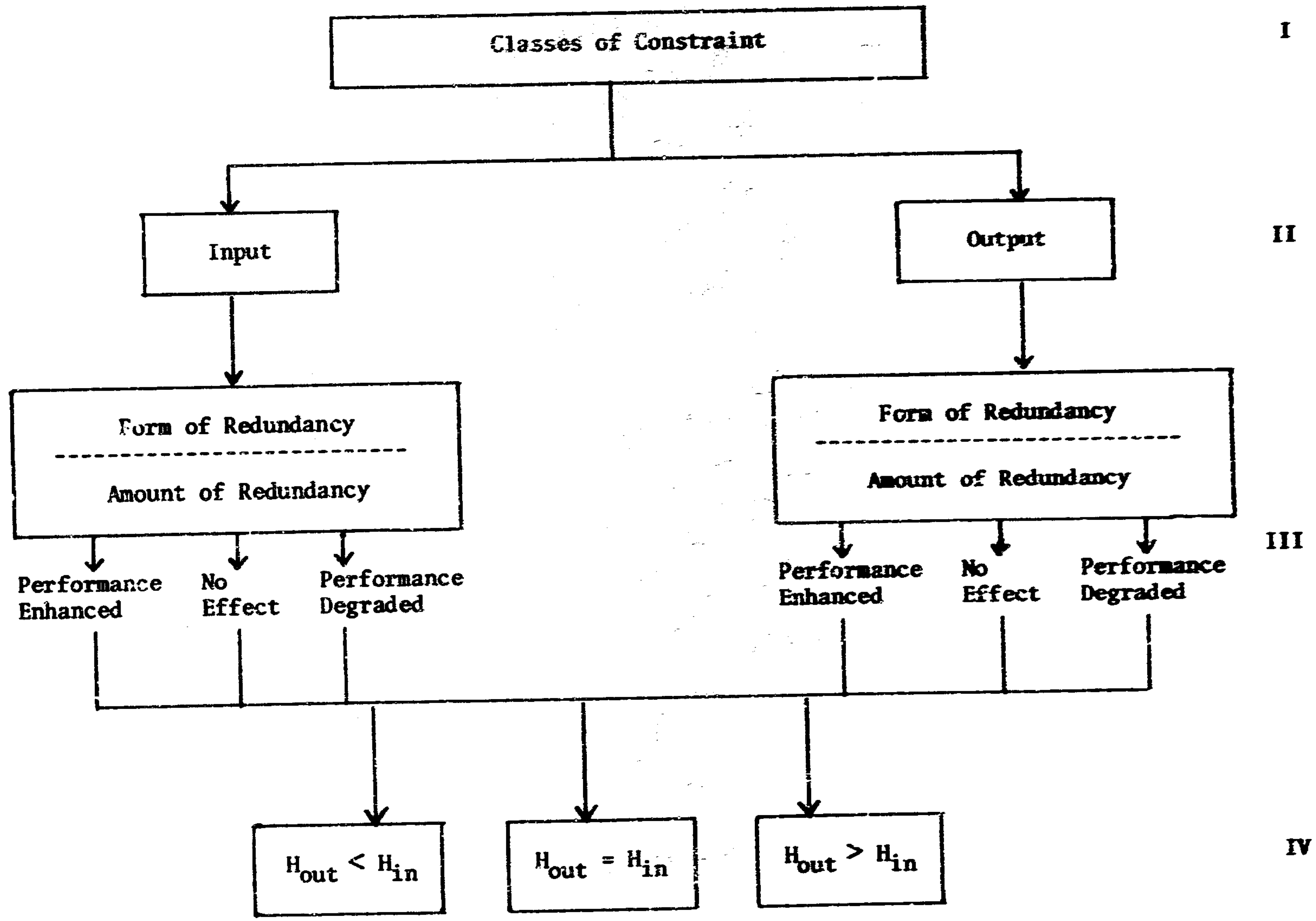
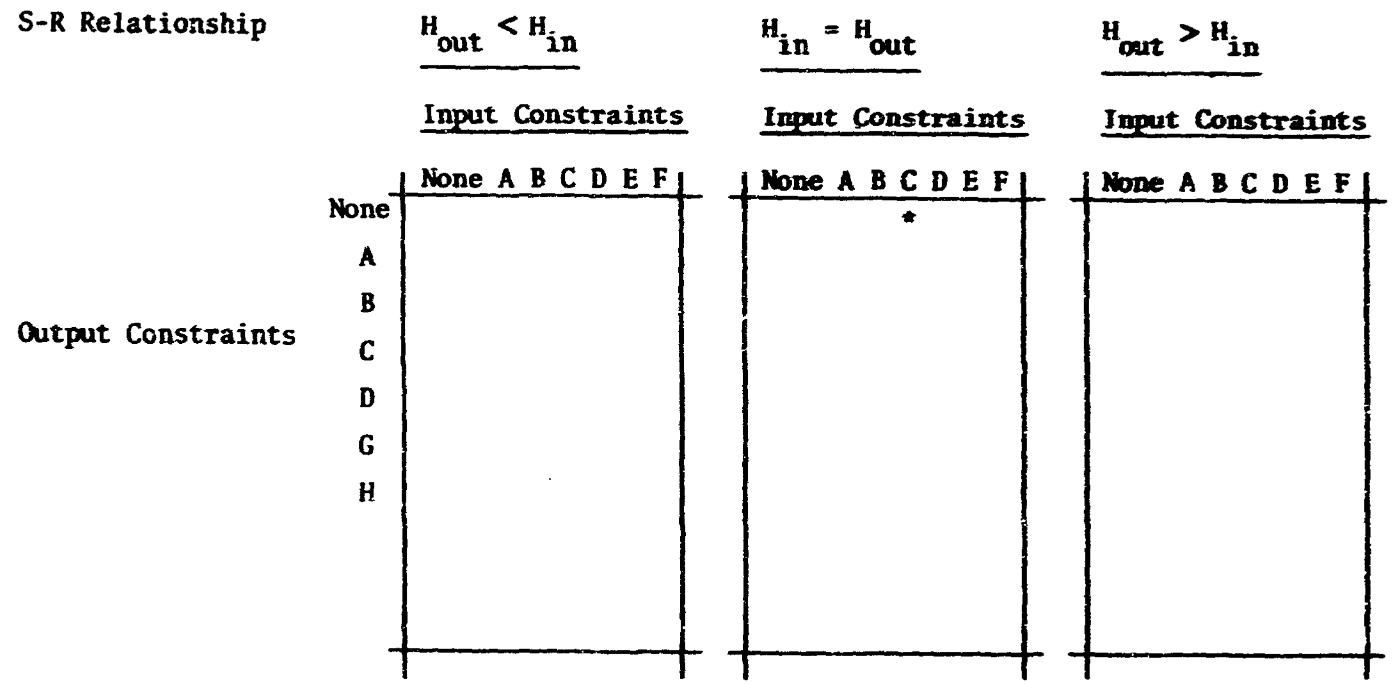


Figure 2. Flow chart depicting dimensions of classification



* For any cell, evaluate the effects of increasing amounts of redundancy upon H_t and classify the task as resulting in either performance <u>enhancement</u> or <u>degradation</u> or <u>no change</u>.

Figure 3. Dimensions of classification according to the information model

between actual and maximum uncertainties expressed as a percentage of present to possible uncertainty ($R = 1 -$ [illegible] max).

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The fourth and final task classification dimension is the relation between quantities of input and output information. In addition to the relationship between amount of redundancy and information transmission within a constraint class, we will be interested in comparing the amount of input information to the amount of output information after task performance is completed. It is possible that output information may be less than, equal to, or greater than input information and the relationship between redundancy and information transmitted may differ as a function of this additional parameter. Furthermore, the tasks themselves may be categorized into those requiring information conservation ($H_{out} = H_{in}$), information reduction ($H_{out} < H_{in}$), or information creation ($H_{out} > H_{in}$), as demonstrated by Posner (1964). Categories within the classification include the following task characteristics:

1. There can be less information in the output than in the input; that is, the amount of information transmitted is less than the maximum possible. This implies constraints present in the receiver not present at the source. For illustration, suppose that it could be determined that a range type of constraint were present and that it could not be accounted for by known range type constraints such as in the eye, the empirical attention span, etc. Under these conditions, it might be inviting to postulate the presence of an underlying mechanism with properties that impose a range type of constraint. We might call this mechanism attention and then we might either develop a model of it which provided the needed constraint or we might try to apply available models--for example, a particular kind of band-pass filter.

2. In an S-R analysis there can be more information at the receiver than at the source. This can happen only if the communication system has more sources than are accounted for. If there is only one external source, other sources must be internal to the receiver. An example of how this could happen might be the following: The input from a second source might be contingent upon the occurrence of events from the first source and the receiver reports both. In this case, if the second source were internal, it might be called memory. Another example might be as follows: Successive inputs from a single source might be operated upon internally to produce a third event and the receiver reports them all. In a human performance situation, the source might present the numerical events 2 and 3, and the receiver might report "2 and 3 are 5." A process that could be postulated to provide this third event might be called computation.

3. Finally, the output information might equal the input information. In this case, there may be no need to assume any receiver constraints to be operating.

Summary of the Model

To summarize, we are taking an information processing approach to task classification. We have a theoretical model which defines a task as an information transfer, we postulate that classes of tasks are characterized by classes of constraints (restrictions on sampling) and that these constraints can be conveniently and rationally dichotomized into constraints upon the source (input) and receiver (output) of the information. Within each class of tasks so defined we propose to characterize tasks further in terms of the effect of amount of redundancy upon information transfer and in terms of the relationship between input and output uncertainty. It is proposed that all tasks falling within a constraint class will be more like one another than tasks in different classes. It is anticipated that all tasks falling within a constraint class will exhibit similar functional relationships between redundancy and information transfer and that these functional relationships will differ across constraint classes. Figures 2, 3, and 4 summarize the model and its dimensions of classification.

If we can establish a valid system of classification based on such an information model, then any new task can be classified on the basis of the constraints imposed on input and output, the amount of redundancy in the stimulus configuration and response ensemble, and the relationship between input and output uncertainty.

We have presented only the barest outline of a task taxonomy model, and that only in terms of some definitions. The model must also have a logic. This is given by a statement of the dependency of information transfer on the constraint classes at different levels of redundancy. The model needs to be developed in detail and then tested against human performance situations. We shall try to indicate briefly how the model can be developed and evaluated.

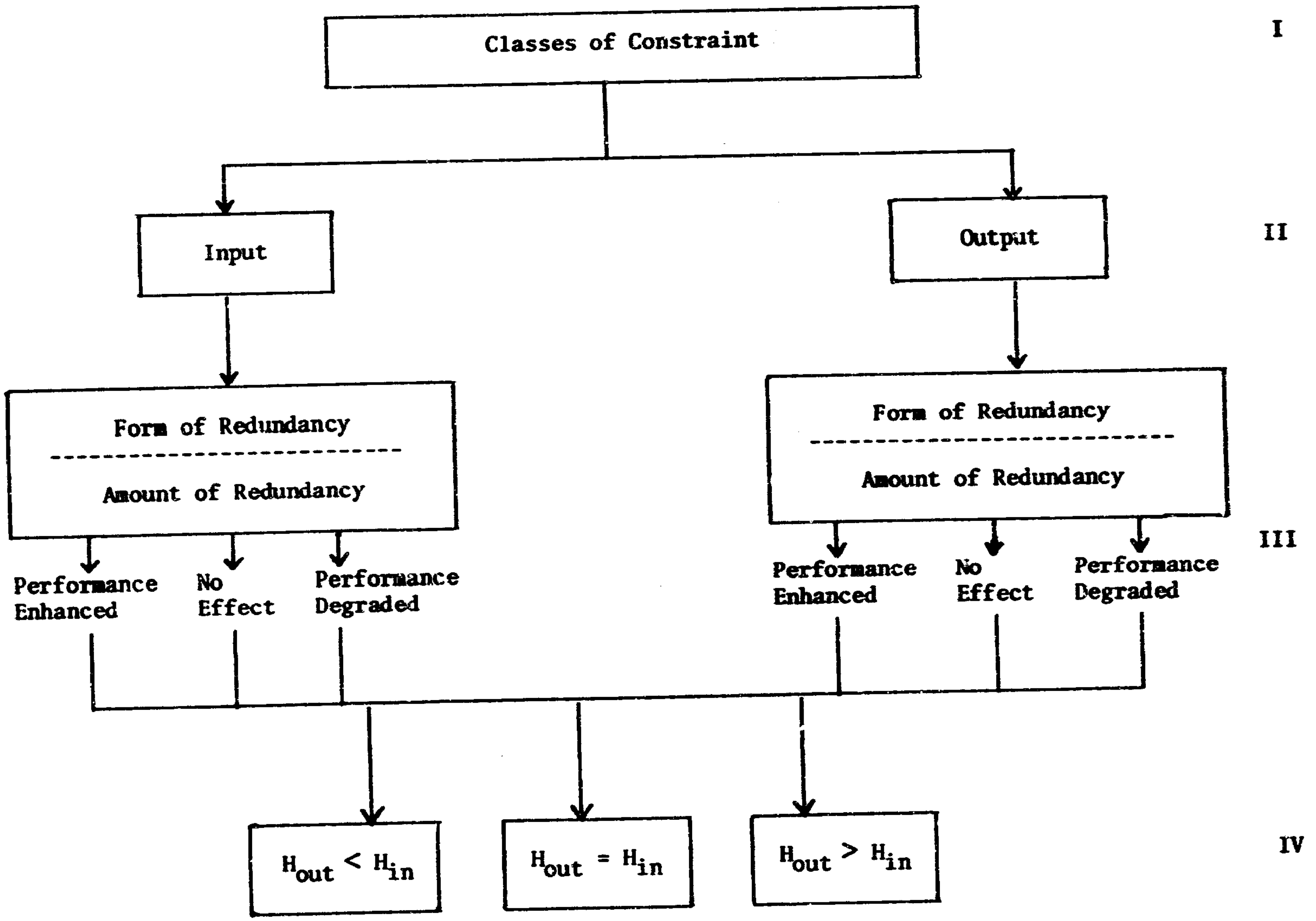
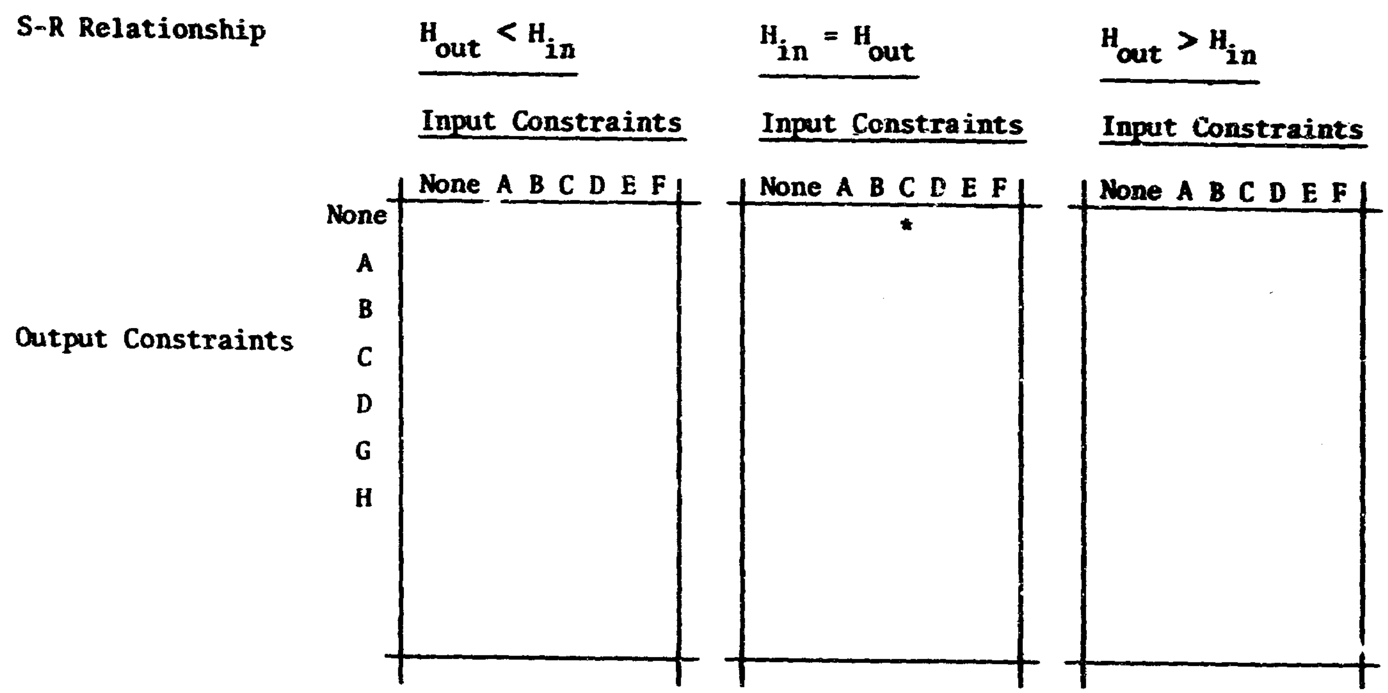


Figure 2. Flow chart depicting dimensions of classification



* For any cell, evaluate the effects of increasing amounts of redundancy upon H_t and classify the task as resulting in either performance enhancement or degradation or no change.

Figure 3. Dimensions of classification according to the information model

Kinds of Constraints

Constraints on input due to restrictions on random sampling of stimuli from source	Constraints on input prescribed by task	Constraints imposed on the subject by the task requirements	Constraints imposed by S due to performance limitations	Constraints imposed on output by task requirements

Model

Source ⟶ Input ⟶ Receiver ⟶ Output

Examples of Constraints

Rules specifying: How stimulus population is sampled? Which stimuli are sampled?	Ensemble Size Presentation Rate Stimulus Range Sequential Spatial Conditional etc.	Add inputs; Respond to every third input; Push spatially corresponding button, etc.	Response Time; Encoding/Decoding Limitations; STM; LTM; etc.	Response Ensemble Characteristics

Specific Example of Task: "Pattern Recognition"

(a) 8 x 8 matrix of lights (b) Pattern is any set of 8 lights such that only one light per column is lit	(a) Patterns come on at a rate of one every 10 seconds for a .5 second duration (b) Twenty different patterns used (c) No pattern can repeat until all are shown	(a) Respond only to those patterns which have four or more rows lit (b) Reproduce pattern by depressing spatially corresponding set of buttons (c) Use one hand and depress only one button at a time	(a) Response time (b) Short term memory (c) Other, undefined	(a) 8 x 8 matrix of buttons

Figure 4. Operation of constraint categories on components of communication model

METHODS FOR EVALUATING THE MODEL

In order to evaluate the feasibility and validity of the model proposed, a twofold iterative approach is envisioned. On the one hand, a strictly theoretical activity must be carried forth by computer simulation of sampling constraints and the determination of the relationship between amount of redundancy and transmitted information (H_t) under a variety of constraint combinations. On the other hand, a series of empirical investigations must be accomplished using tasks which allow the experimenter to manipulate input constraints and require the subject to provide output constraints. The influence of redundancy upon information transmission must be determined empirically and compared to the results of the computer simulation. If agreement is found, there would be evidence for the viability of the system.

The Specification of Constraints

Constraints may be stated as sampling rules. Examples of classes of such rules may be found in sequential sampling restrictions, e.g., purposive sampling, stratified sampling, and sampling without replacement. Examples of possible classes of constraints are:

1. Combination constraint--sample only n at a time.
2. Rate constraint--sample no faster than a given rate.
3. Range constraint--sample only within a specified range of values.
4. Similarity-dissimilarity constraint--sample only combinations having no common elements.
5. Probability constraint--sample only events having probabilities greater than a specified probability.
6. Sequence constraint--sample only sequences having some specified sequential restriction, e.g., no unique event can occur twice in succession.

A theoretical requirement is the specification of all of the possible sampling constraints. An experimental requirement is that of determining which of these possible constraints are represented in the human receiver.

Most human performance situations are likely to be those in which the man provides output constraints. Sources of human external constraints are indicated by the spectral sensitivity of the eye and ear, size of the visual field, empirical attention span, memory span, coordinative ability, etc. All of these act to limit the reception of transmitted events. Application of the model requires finding out what classes of constraint man can represent. The next step is to identify the sources of the human-imposed constraints. Doing this requires research which is directed toward evaluating how well people can represent the constraints in the presence of sources which themselves are varied in kind of constraint imposed.

Both the theoretical and experimental approach to evaluating the model must be quite restricted. The following limitations must be imposed upon any initial research effort.

1. While it is necessary for all possible classes of constraints to be specified for the proposed system to be operational, only a few input and output constraints should be dealt with initially.
2. It is possible for a task to involve multiple input and output constraints in a variety of combinations. For the purpose of initial evaluation, we must restrict our concern to the simultaneous operation of a single input and single output constraint or no constraint at all and combinations of these alternatives.
3. We plan to deal only with discrete tasks even though the model proposed is applicable to any kind of task.
4. Initially, we will consider only constraints that are easily quantifiable in task situations wherein the input and output are easily quantified.

The above limitations are imposed in order to evaluate the model under relatively simple circumstances and those most easily applicable. If the model proves viable under these circumstances, we will be encouraged to pursue it further. If, on the other hand, the model proves to be invalid, it can be modified or discarded on the basis of a minimal research effort.

We are interested in determining which classes of constraint exist in human performance situations. This may be determined by evaluating the performance of individuals supposedly operating with a specified constraint against the theoretical outcome of the constraint upon random sampling. Once we have demonstrated that a constraint operates, it remains to consider the effect upon performance and information transmission as redundancy is varied. Our basic postulate is that the effect of any constraint upon performance is a function of the redundancy introduced by that constraint.

The manipulation of redundancy is accomplished by maintaining actual stimulus uncertainty constant and varying maximum stimulus uncertainty. In this manner, the influence of redundancy is not confounded by the possible effects of actual stimulus uncertainty. Redundancy is more of a problem when one considers output constraints. Redundancy cannot be manipulated since it is determinable only "post" performance. It will be necessary to compute H_t under several conditions of maximum response uncertainty, and then determine the amount of redundancy in the output information as well as the amount of transmitted information.

Approach to Evaluating the Model

Our approach consists of a determination of the theoretical influence of constraint classes upon H_t and simultaneous empirical investigation designed to evaluate whether or not these constraint classes operate in human performance and to assess the influence they exert on the performance. The theoretical activity to be accomplished by computer simulation is comprised of the following steps.

1. Postulate a task having a 1:1 input-output relationship.
2. Impose a constraint (sampling rule) upon the stimulus population or response population or both, with the initial population consisting of equiprobable alternatives.
3. Sample combinations of stimulus and response alternatives according to the constraint rules.
4. Generate an output of frequencies of occurrence of computer-drawn samples.
5. Compute H_t.
6. Repeat to get an average H_t and $\sigma^2 H_t$.
7. Compute $H(x)$, $H(y)$, $1-H(x)/H_{max}$.
8. Using the same constraint, repeat steps 2 thru 7 manipulating amount of input redundancy (through changes in maximum uncertainty).
9. Plot H_t as a function of redundancy for the constraint class.
10. Repeat steps 2 thru 9 for 1:n and n:1 relationships.
11. Repeat steps 1 thru 10 for additional constraints.

Our early laboratory effort was designed to identify and implement a task which was discrete and allowed for the modification of selected input and output such that all specified constraints could be manipulated. Given such an environment, a series of experiments were planned aimed at answering three general questions:

1. What kinds of human constraints operate and what is their effect on performance?
2. What kinds of experimenter-imposed constraints influence performance and in what manner?
3. Do the laboratory results agree with the theoretical results?

If the results do not agree, we will ask what constraints the subject could be imposing on the task in order to generate the results obtained. We will attempt to introduce such postulated constraints in a new computer simulation to determine if the theoretical outcome can be matched

to the performance data. Several such iterations will permit the identification of subject-imposed constraints which then would require validation.

Evaluations have been planned, to be conducted on an iterative basis, in an attempt to match experimental and computer results and thus identify the nature of the subject-imposed constraints, their effects upon performance, and the functional relationships between input redundancy and information transmission for the different constraint classes.

Experimental Tasks Developed

A Sequential Information Processing Programmer (SIPP, Figure 5) was developed as the vehicle for the experimental studies considered necessary to evaluate the model. This device permits the automatic time-controlled presentation of discrete visual stimuli. The stimulus ensemble consists of an 8 x 8 matrix of lights which may be presented with or without a grid and may be reduced in size to any n x m configuration. The response console is an 8 x 8 matrix of buttons, compatible with the stimulus ensemble. The input-output devices are tied into logic circuitry and recorders such that stimulus sequences may be prepared in advance on punched paper tapes, and responses along with their latencies may be recorded onto punched tape as they occur. The relationship of lights to buttons may be conveniently manipulated into any desired unique or overlapping correspondence. The apparatus has the flexibility to permit the imposition and manipulation of a wide variety of constraints. The nature of any particular task will be determined by the S-R relationship established.

Three experiments have been conceptualized, each to be conducted iteratively with a corresponding computer simulation. These studies will consider signal detection, pattern identification, and pattern classification tasks. While the details of these studies have not yet been formulated, all three will deal with two specific constraints on

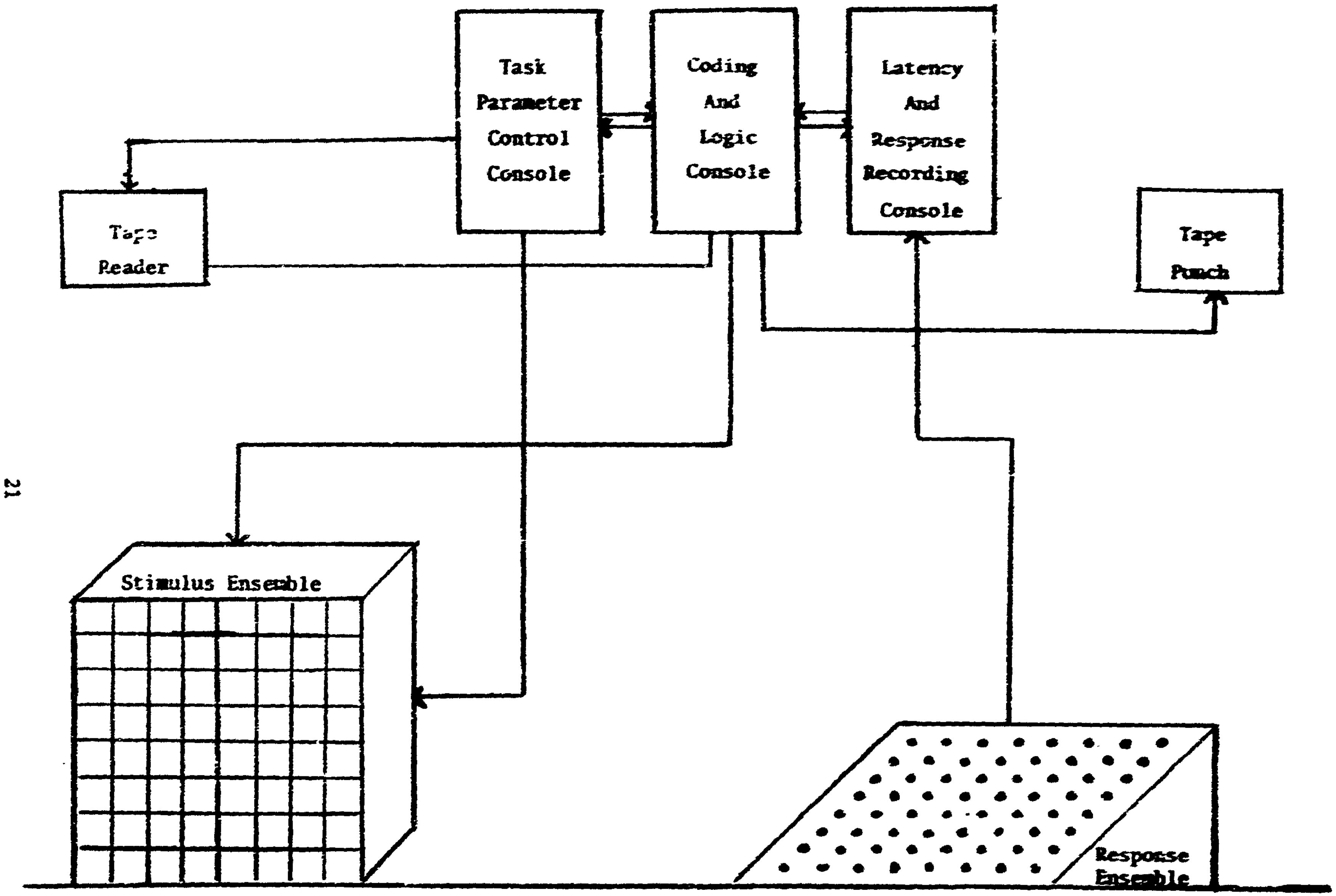


Figure 5. Illustration of Sequential Information Processing Programmer

the input as well as subject-imposed constraints. Stimulus redundancy will be the primary independent variable. In general, subjects will be required to perform a discrete information processing task while input constraints and redundancy are varied. Performance, in terms of transmitted information, will be evaluated and compared to outcomes of the associated computer simulations.

CONCLUSIONS AND IMPLICATIONS

The taxonomic approach described above differs from most other methods of developing a taxonomy in that it is based on a general model which starts with a set of definitions, relationships, and classes and has meaning in the same sense that a mathematical or logical system has meaning. That is, the system is complete before any attempt is made to apply it to observations. It is *a priori* rather than *a posteriori*. The model which we have selected for use is an information theory model. We are seeking to use this model as a taxonomic system which describes classes of general relationships among input and output phenomena.

We are not particularly concerned with the use of the model as a basis for describing the processes which underlie these relationships, nor are we interested in a description of tasks as defined by the involvement of underlying processes, although the model does not preclude such interests. We are interested in the model as a means for classifying tasks qua tasks.

Because the idea represents a new insight about a generally-used mathematical system, there was a need for a careful evaluation of its components for our purposes. As a consequence, most of our effort thus far has been devoted to the matter of definition and of identification of those aspects of the model of greatest relevance. Although we are convinced about its general utility, its specific utility must be demonstrated.

It is important to realize that, aside from its general potential as a scientific tool, a major advantage of this particular approach, if it can be developed adequately, is the possibility of classifying any new or modified task. Furthermore, performance on such tasks may be estimated by computer simulation techniques if factors which restrict performance (i.e., constraints) are properly identified and described. In reverse, it may be possible to simulate any new hypothesized task given a knowledge of the ways in which human performance is limited.

Thus, this approach dovetails completely with the other provisional classification systems developed under the project by providing a mathematical framework within which abilities and other performance-limiting factors can operate predictively. This effort is consistent with our intention of providing a bridge between the general scientific study and the applied need.

It must be emphasized that the adaptation of an information model to task classification allows for the translation of the concepts and findings of the "ability requirements" and "task characteristics" approaches into a common systems language of relevance to design engineers and military system equipment planners. Additionally, this language permits human performance and machine performance to be specified in terms of identical parameters by systems personnel.

Once we have demonstrated the viability of our model, further development of our system for task classification will be concerned primarily with two major efforts. One effort will center about the preparation of a Systems Language Manual which would specify the classes of constraints which might operate in human performance tasks and the effects upon performance of such constraint classes (i.e., the performance limitations imposed by the constraints). These relationships will be hypothetical, determined in most cases on the basis of computer simulation of constraint effects upon information transmission as redundancy is varied. Our second major effort would involve the initiation of a translation of the ability requirement and task characteristic approaches into the systems language. In effect, this will be a specification of the kinds of task and operator variables affecting performance and the degree to which these variables impose limitations upon performance. Future plans call for evaluative efforts to be conducted on our integrated system.

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